Endovascular approaches to complex aortic aneurysms

de Niet, Arne

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CHAPTER 9

Geometric changes over time in bridging stents after branched and fenestrated endovascular repair for thoracoabdominal aneurysm

Arne de Niet
Richard B. Post
Michel M.P.J. Reijnen
Clark J. Zeebregts
Ignace F.J. Tielliu

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Abstract

The objective of this study was to assess long-term durability of bridging stents in branched and combined branched and fenestrated endovascular aneurysm repair (B/F-EVAR) for thoracoabdominal aortic aneurysm (TAAA) and pararenal abdominal aortic aneurysm.

A retrospective database analysis was performed of patients treated by B/F-EVAR for TAAA. Computed tomography angiography images were analyzed to assess patency, bridging stent angulation and migration, aneurysm diameter, and migration of the endograft.

Twenty-eight patients with a median age of 70 years (interquartile range [IQR], 67-77 years) were included. Assisted technical success was 89%. Within 30 days postoperatively, five patients died. In the remaining 23 patients, median follow-up was 5.3 years (IQR, 2.9-7.2 years), and 1-, 3-, and 5-year estimated overall survival was 69%, 65%, and 44%, respectively. During follow-up, 12 of 47 (26%) branches occluded and 5 of 47 (11%) branches developed a 70% to 99% stenosis. The 1-, 3-, and 5-year estimated freedom from adverse events was 78%, 76%, and 59% for branch stents and 100%, 96%, and 90% for fenestration stents, respectively. The median distal bridging stent migration was 0.5 mm (IQR, —1.9 to 1.4; P > .05 mm). In 10 branches, migration >10 mm was seen, ranging from 14.1 mm sliding in to 23.0 mm sliding out. The angulation between branch and stent became 4 degrees more angulated (IQR, —14 to +2 degrees). In 23 branches, the angulation changed 10 degrees or more, leading to an occlusion in 7 branches, a 70% to 99% stenosis in 3 branches, and a 50% to 70% stenosis in 4 branches. In three cases, the endograft migrated >5 mm caudally, with a breach in a fenestration stent in one and a breach in a branch stent in another.

The anatomic configuration of branches in B/F-EVAR of TAAAs and pararenal abdominal aortic aneurysms changes over time. The change in angle of branches and the bridging stent influences the likelihood of stenosis and occlusion. Follow-up of B/F-EVAR should include computed tomography angiography measurements of aortic diameter, endograft migration, target vessel stent length, and angulation to detect disconnection, stenosis, and occlusion.

Introduction

The natural history of patients with an untreated thoracoabdominal aortic aneurysm (TAAA) is associated with considerable mortality. In a survey by Hansen et al[1] concerning 89 patients with a TAAA unfit for surgery, 26% of patients died of rupture within 2 years. On the other hand, another study showed an overall mortality after open repair of 22%, with at least one postoperative complication in two-thirds of patients.[2]

Thoracic endovascular aortic repair can be an alternative to open repair, but it is unsuitable when the TAAA or pararenal abdominal aortic aneurysm (pAAA) incorporates visceral arteries. To secure flow to the visceral arteries, Chuter et al[3] introduced a branched endovascular system in 2001. Within this system, directional side branches created a fixation zone in which covered stents were placed to bridge the gap to the target vessel. Since 2001, several studies have been published regarding the clinical outcome of branched and combination branched and fenestrated endovascular aneurysm repair (B/F-EVAR).[4-8] Technical success ranged between 87% and 100%, depending on the device design.[5,6,8-10] However, in most studies, follow-up was short.[4,5,8,11,12] Midterm follow-up (21-36 months) was reported in only three studies.[13-15] Bridging balloon-expandable and self-expandable stents in both branches and fenestrations have been shown to be durable in the long term, but a detailed description of changes in stent configuration, fracturing, kinking, and migration over time is lacking.[14,16] Knowledge of the branches' mechanical behavior in the long term can help prevent the occurrence of complications by timely reintervention.[17] The aim of this study was to present results on durability of bridging stents after B/F-EVAR in the longer term and the relation with geometric behavior in time.

9

Methods

A retrospective review of a prospectively held electronic database was conducted in a university medical center. All patients with a TAAA or pAAA involving the visceral arteries treated with B/F-EVAR between November 2004 and June 2011 to have adequate follow-up were included. Patients were treated if they had a maximal diameter >60 mm for the thoracic component, >55 mm for the abdominal component in men and >50 mm in women, >5 mm aneurysm growth during a 6-month period, and presence of a saccular aneurysm or an anastomotic false aneurysm.

Details about the procedure and early results have been published before.[6,18,19] To prevent spinal cord ischemia, spinal drainage was performed at 10 mL/h for 72 hours in combination with maintaining the mean arterial pressure at a level of 90 mm Hg. Based on thin-cut (0.75-mm axial slices) computed tomography angiography (CTA), a customized three-part Cook Zenith System (Cook Medical, Bloomington, Ind) was manufactured. Branch design is usually standard, being 18 or 21 mm in length, depending on the distance to the target vessel, and 6 or 8 mm in diameter, depending on target vessel diameter. The length of the bridging stent was chosen to fully cover the branch from within to bridge the distance between the branch and the origin of the target vessel and approximately 20 mm of stent length inside the target vessel. Covered balloon-expandable stents were used to bridge between branch or fenestration and target vessel. Nitinol self-expandable stents were used to support the bridging stent when required. Follow-up included CTA (0.75-mm axial slices) and outpatient visit at 6 weeks and annually or earlier in case the clinical presentation suggested a device-related adverse event.

Data were gathered on survival, reinterventions, and adverse events to the branches and fenestrations. Bridging stent-related adverse events included 50% to 99% stenosis, occlusion, disconnection, and breach of the stent in the target vessel. Measurements were performed by two investigators (A.N. and R.B.P.) using a three-dimensional volume rendering postprocessing software package (Aquarius iNtuition, version 4.4.7; TeraRecon, Foster City, Calif). The variables were documented on the first postoperative and last available CTA study, as follows:

- Branch or bridging stent patency was classified as no stenosis up to 49%, 50% to 99% stenosis, or occlusion.
- Length of the bridging stent outside the branch or fenestration was measured on a manually adjusted central lumen line (CLL) using the distance between the end of the stent and the distal marker of the branch or the marker of the fenestration. Sliding in was defined as a decrease of stent length, and sliding out was defined as an increase of stent length with regard to branch or fenestration markers.
- Angulation of the branch or bridging stent in degrees was the most prominent angle in a branch or fenestration stent measured with the CLL. A straight CLL measured 0 degrees, counting toward 90 degrees in increased angulation.
- Displacement of the body of the endograft measured the caudal displacement relative to an adjacent vertebral body bone landmark.

- Size of the aneurysm was the largest aortic diameter measured perpendicular to the aortic CLL.

Results, including endoleaks, disconnections, and complications, were presented following the recommendations by Chaikof et al.[17,20] The study protocol was approved by the local Medical Ethics Committee (2014/ 425), and data were analyzed anonymously.

Statistical analysis

Given the relatively small cohort size, data are presented as median with interquartile range (IQR). Statistical analysis was done with the Mann-Whitney U test in unpaired data and the Wilcoxon signed rank test in paired data. Survival and freedom from adverse events of the branches and fenestrations were analyzed by Kaplan-Meier survival curves. Relations between variables were analyzed by univariate regression analysis. Statistical analysis was performed with SPSS software (version 22; IBM, Armonk, NY), and $P < .05$ was considered statistically significant.

Results

Patients' demographics. Twenty-eight patients underwent B/F-EVAR for large aneurysm size (n = 21), saccular aneurysm (n = 2), or anastomotic false aneurysm (n = 5); none had a rapid growth TAAA. Median age at operation was 70 years (IQR, 67-77 years), and 20 patients were male (71%). Median preoperative estimated glomerular filtration rate was 73 mL/min/1.73 m2 (IQR, 56-89 mL/min/1.73 m2). All risk factors are shown in Table I.

TABLE I: PATIENT RISK FACTORS (N = 28)

Risk factor	No. (%)
Diabetes mellitus	3 (11)
Hypertension	26 (93)
Cardiac disease	16 (57)
Symptomatic pulmonary disease	16 (57)
Cerebrovascular disease	3 (11)
Recent (<1 year of abstinence) or active smokers	17 (61)
Past smoker (>10 years stopped)	11 (39)
Hypercholesterolemia	15 (54)
ASA class	
2	15 (54)
3	12 (43)
4	1 (4)

ASA, American Society of Anesthesiologists

Seven patients were previously operated on for an abdominal aortic aneurysm, five with an open aortobi-iliac and two with an open aortic tube graft implantation. Aneurysms were classified according to Crawford et al21: type I, n = 4; type II, n = 7; type III, n = 12; and type IV, n = 3. The remaining two were considered pAAAs.

Operative results

The designs of the endografts are summarized in Table II. In 10 patients, the endograft design included only branches; in 18 patients, a combination of branches and fenestrations was used. Configuration of the branches, fenestrations, and stents is shown in Table III. To connect the target vessel, a balloon-expandable covered stent was mainly used as a first bridging procedure, and when necessary to smooth the angulation in the covered stent or between stent and target vessel, a self-expandable stent was used thereafter.

All procedures were done with cutdown of the access vessels in the groin (common femoral artery) and the arm (axillary artery). In two cases, a conduit to the iliac artery was used. Median blood loss was 400 mL (IQR, 250-500 mL); operation duration, 300 minutes (IQR, 275-360 minutes); fluoroscopy time, 80 minutes (IQR, 62-93 minutes); and contrast material volume, 320 mL (IQR, 245-350 mL). There were no cases with documented contrast nephropathy or skin burns due to the high fluoroscopy times and contrast material volumes. The technical success rate was 82%, with an assisted technical success of 89%. One patient died as a result of an intraoperative aortic arch rupture before the endograft was deployed. In a second patient, the left renal artery (LRA) was perforated by manipulation of the guidewire intraoperatively. The bleeding was treated by stenting of the renal artery covering the perforation, and it was considered assisted technical success. In one patient, connection between branch and celiac trunk (CelTr) could not be achieved, and this was considered a technical failure. The CelTr was overstented with an aortic cuff and collateral circulation prevented clinical consequences. In another case, the bridging stent for the LRA had dislodged from the balloon and could not be retrieved, and another stent was successfully placed. During follow-up, the LRA remained open. In one case, a type IA endoleak was accepted and considered a technical failure. Two patients had a type II endoleak, both of which were accepted and spontaneously disappeared within 1 year.

TABLE II: SUMMARY OF ENDOGRAFT DESIGN

	No.	Median	IQR
Top diameter, mm	28	34	32-38
Length of endograft, mm	28	227	190-243
Distal diameter, mm	28	24	22-31
Branches, mm	59		
CelTr	24	8	-
SMA	18	8	-
LRA	11	6	6-7
RRA	9	6	6-8
Fenestrations, mm	34		
CelTr	1	8	-
SMA	7	8	-
LRA	10	6	6-8
RRA	14	6	6-8

CelTr, Celiac trunk; IQR, interquartile range; LRA, left renal artery; RRA,right renal artery; SMA, superior mesenteric artery. Values are presented as median or the number of cases. The median diameter of the branch or fenestration is presented; when the branches or fenestrations have the same diameter, no IQR is presented.

TABLE III: STENTS USED FOR BRANCHES AND FENESTRATIONS IN 28 PATIENTS

	Branched								Fenestrated								Branched		Fenestrated		
	CelTr		SMA		LRA		RRA		CelTr		SMA		LRA		RRA		Total		Total		Stents
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	Total
Absolute								1										1			1
Advanta V12	22		18	4	10	3	8	1			7		9		13		58	8	29		95
E-Luminexx		2		2								1						4		1	5
Fluency				1														1			1
Jostent									1	1			1		1	1			3	2	5
Smart		11		7		4		3								1		25		1	26
Wallstent		3		2	1			1									1	6			7
Zilverstent		1		2		3		1				1						7		1	8
Total	22	17	18	18	11	10	8	7	1	1	7	2	10	0	14	2	59	52	32	5	148

CelTr, Celiac trunk; LRA, left renal artery; RRA, right renal artery; SMA, superior mesenteric artery.
The first stent was used to cannulate the target vessel, and if necessary, a second stent was used to elongate or to strengthen the branch or stent.
The stents used were Absolute Pro (Abbott Vascular, Abbott Park, Ill), Advanta V12 (Atrium, Merrimack, NH), E-Luminexx (Bard, Tempe, Ariz), Fluency (Bard), Jostent (Abbott Vascular), SMART (Cordis, Miami, Fla), Wallstent (Boston Scientific, Marlborough, Mass) and Zilver (Cook Medical, Bloomington, Ind).

Postoperative results

Thirty-day mortality was 18% (5/28), including the patient who died intraoperatively. Another patient thought to have mesenteric ischemia deteriorated rapidly and died before diagnosis by CTA was possible. A third patient developed transmural ischemia of the left hemicolon and died of cardiac failure after resection. In both patients, no permission for autopsy was given. A fourth patient was transferred to a nursing home for rehabilitation, refused further therapy, and stopped eating and drinking; combined with an already poor physical condition, he died 25 days postoperatively. Finally, one patient died of unknown cause.

One patient developed permanent incomplete paraplegia despite spinal drainage, and one patient had temporary spinal cord ischemia that disappeared after spinal drainage. One patient was treated surgically for a large hematoma in the groin. Two patients developed a thromboembolic complication in the access arm and needed surgical thrombectomy and patch plasty. Both patients had permanent paresis as a result of damage to the brachial plexus. No other cardiac failure or stroke was seen during the 30-day postoperative period.

Follow-up survival.

All-cause mortality including the 30-day postoperative period was 64% (18/28). The estimated 1-, 3-, and 5-year survival was 70%, 67%, and 50%, respectively (Figure 1).

Median follow-up of the 23 patients surviving the 30 day postoperative period was 5.3 years (IQR, 2.9-7.2 years). Nine patients died of nonaneurysm-related causes (39%), and four patients (17%) died as a result of aneurysm-related causes at 47, 52, 69, and 71 months. The first patient had complete occlusion of the abdominal aorta and died despite thrombolysis. The second patient had an acute type IA and type III endoleak from the CelTr branch. He died 2 weeks later of mesenteric ischemia despite cuff placement and relining of the CelTr. The

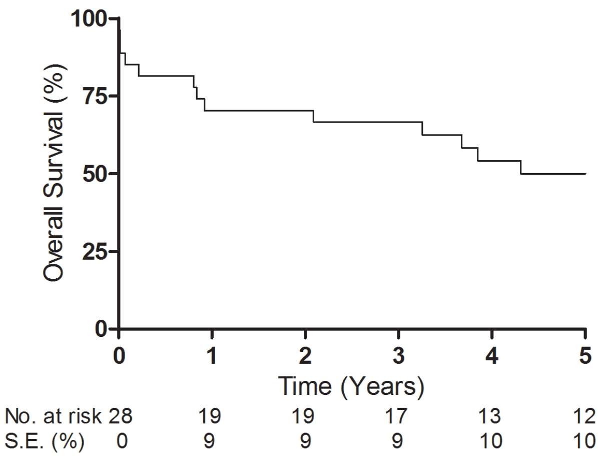


Figure 1: Estimated cumulative overall survival. S.E., Standard error.

third patient had occlusion of the right renal artery (RRA) and superior mesenteric artery (SMA) at 5.7 years and subsequently died. The last patient presented with an occlusion of both renal arteries and CelTr at 3.7 years postoperatively. A bypass from the external iliac artery to the LRA was made, but it occluded soon afterward, subsequently necessitating hemodialysis. At 5.8 years after initial operation, the SMA occluded as well, and the patient died of mesenteric ischemia.

Follow-up reinterventions

Five reinterventions were performed after 30 days. Reinterventions included the placement of a stent in the CelTr for mesenteric ischemia at 2 months and a cuff at 52 months, which was mentioned before. Another patient had insufficient distal sealing, and a distal extension was placed 3 months post-operatively. In a third patient, a cuff was placed at 40 months to seal a type III endoleak between two components of the endograft. In another patient, an external iliac artery to LRA bypass was made at 3.7 years. The last patient, with an occlusion of the endograft, underwent thrombolysis at 3.8 years.

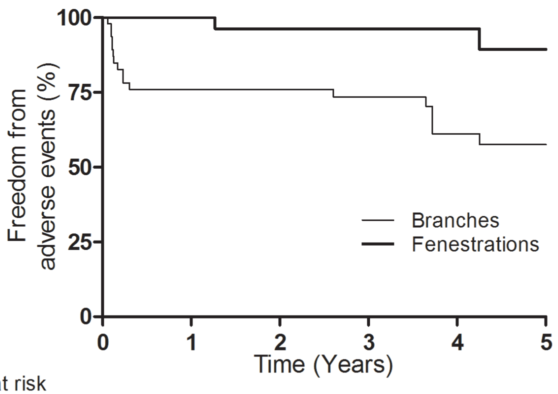
Aneurysm sac size

Median aneurysm diameter change from preoperatively (61 mm) to last follow-up was 6 mm of shrinkage (IQR, 2 mm of growth to 15 mm of shrinkage; P = .035). There was aneurysm shrinkage in 14 cases and increase of 2 to 4 mm in 4 cases. In three cases, aneurysm size increased >5 mm. The first had an increase of 8 mm at 8 years and the second of 10.5 mm at 5.8 years of follow-up, both without clinical consequences and left untreated. In the other case, an increase of 19 mm at 52 months was presumably due to a type IA endoleak and treated with an aortic cuff as mentioned before. Two cases were excluded from this analysis because no late CTA was available.

Follow-up patency of branches and fenestrations

Analysis of branches and fenestrations was performed on the 23 patients surviving the 30 days, but in two cases, no late CTA was available. Consequently, measurements were done in 47 branches and 28 fenestrations.

During median follow-up, 10 of 47 branches (21%) occluded and 10 of 47 branches (21.3%) had a 50% to 99% stenosis. Estimated cumulative freedom from adverse events in cases with



No. at risk						
Branches	47	33	31	29	18	16
S.E. (%)	0	6	6	6	8	8
Fenestrations	28	27	26	22	18	11
S.E. (%)	0	0	4	4	4	7

Figure 2: Estimated cumulative freedom from adverse events for target vessels in cases with available follow-up after 30 days postoperatively, separated for branches and fenestrations. S.E., Standard error.

available follow-up after 30 days postoperatively for branches at 1 year, 3 years, and 5 years was 78%, 76%, and 59%, respectively (Figure 2).

One patient, described in the survival section, had an occlusion of both renal arteries and CelTr at 3.7 years and occlusion of the SMA branch at 5.8 years. In another patient, both renal arteries occluded at 2.8 months post-operatively, requiring hemodialysis. In a third patient, the RRA occluded and the LRA had a 50% to 99% stenosis at 3.7 months before treatment was considered, and this resulted in hemodialysis. The CelTr had a 50% to 99% stenosis in this same patient, but collateral mesenteric circulation was sufficient to prevent clinical consequences. In the remaining cases, there were seven branch occlusions or 50% to 99% stenosis in CelTr (n = 4), SMA (n = 1), and LRA (n = 2). Collateral mesenteric circulation or acceptable renal function allowed watchful waiting in these cases. In one branch, a kink was noted, resulting in a 50% to 99% stenosis, and in one SMA branch, the stent breached, leading to 50% to 99% stenosis, both without clinical consequences.

One of the 28 fenestration-related stents breached, leading to a 50% to 99% stenosis of the SMA at 10.3 years. Another patient with the type IA and type III endoleaks, mentioned several times, had a disconnected stent in the CelTr fenestration that was relined at 2 months. In one patient, the RRA fenestration occluded at 5.7 years with occlusion of the SMA branch, mentioned in the survival section. In another patient, the LRA had a 50% to 99% stenosis without clinical consequences. In total, there were 2 of 28 (7.1%) occluded fenestration stents and 2 of 28 (7.1%) with a stenosis of 50% to 99%. Estimated cumulative freedom from adverse events in cases with available follow-up after 30 days postoperatively for fenestrations at 1 year, 3 years, and 5 years was 100%, 96%, and 90%, respectively (Figure 2).

Migration of the bridging stent

The median length of the stents outside the branch was 48.7 mm (IQR, 42.4-56.3 mm). The median migration of the bridging stents during follow-up was 0.5 mm sliding out the branch (IQR, —1.9 to 1.4 mm; P = .513). In 10 branches, migration >10.0 mm was seen, ranging between 14.1 mm sliding in and 23.1 mm sliding out. In two of those cases, this possibly led to occlusion of the SMA (—8.9 mm) and LRA (13.0 mm). In another case, both the SMA (þ11.0 mm) and LRA (þ17.1 mm) slid out, and a relining was necessary because of a type III endoleak. In the 23.1-mm slid out stent, a combination of a bridging stent with a supporting stent was used.

In the fenestrations, the median stent length outside the fenestration was 14 mm directly postoperatively (IQR, 12-26 mm) and during follow-up remained 14 mm (IQR, 12-28 mm). There was no overall change noted (IQR, —1 to 1 mm; P = .158).

Angulation

The median angle between the branch and its bridging stent became 4 degrees more angulated over time (IQR, -14 to +2 degrees; P = .026). In 23 of the 47 branches, the angulation change was 10 degrees or more, ranging up to 41 degrees of more angulation and up to 30 degrees of straightening. In four cases with an increased angle (15, 15, 30, and 41 degrees), an occlusion was noted; in seven cases with an increased angle (13, 15, 16, 17, 17, 19, and 25 degrees), a stenosis of 50% to 99% was noted. All those cases were in different patients, and no relation between angulation and occlusion or stenosis was found (P = .129). In one patient, the angle of bridging stents in the CelTr, SMA, and LRA straightened (20, 15, and 30 degrees) simultaneously with occlusion of the stents.

The median angle of fenestration stents changed with -1 degree (IQR, -7 to 8 degrees; P = .808). In four cases, the angle increased >10 degrees (12, 17, 22, and 25 degrees); in one of these cases, the SMA stent breached, leading to a stenosis of 50% to 99%, without clinical consequences. In five cases, the stent straightened 10 degrees or more (10, 11, 12, 14, and 15 degrees), and a straightened RRA of 10 degrees occluded. In this patient, the SMA branch occluded, and the patient died of mesenteric ischemia.

Migration of the branched main body

In five patients, >5 mm of caudal migration of the main body was found (range, 5.2-12.8

mm). In three patients, cranial displacement was >5 mm (range, 8.3-12.4 mm. Overall, no migration was seen (P = .355). In one case, the endograft migrated 11 mm, leading to a breach of the fenestration stent; and in another case, the endograft migrated 5 mm, leading to a breach in a branch stent. Visceral aorta angulation (P = .122), preoperative TAAA diameter (P = .793), aneurysm sac change (P = .108), and endograft length (P = .864) were not significantly related to endograft migration.

Discussion

This study describes the geometric changes of bridging stents in branches and fenestrations after B/F-EVAR for TAAA and pAAA in a median follow-up period of 5 years. The angle of the branch stents changed and led to stenosis or occlusion of stents in 11 cases. In this small series, the mere angle was not an indicator of occlusion in itself; in nine branches, angulation changed >10 degrees and remained open. However, in some cases, the angle changed, and an increased angle could mandate a closer follow-up or early reintervention to ensure stent patency. Large changes in angulation over time might be a result of movement of the endograft relative to the target vessels, as was seen in a few cases in our study and supported by previous published literature.[22] Migration of stents in both branches and fenestrations seems to elicit stenosis or occlusion. In one patient, a gradual outward migration of the branch stents of the SMA and LRA was seen, creating a disconnection and type III endoleak. This was successfully secured by a new bridging stent. Both disconnections could have been prevented by an even more meticulous measurement of the length of the bridging stents on the postoperative CTA images.

We were not able to identify the individual (bare-metal and covered) stents because the overlap of the struts makes it impossible to identify the exact edges of the stents. Possibly, some stents slide in and out of each other. The sliding of stents is more evident in branches than in fenestrations (10 vs 1, respectively). The difference is probably related to the flaring of the stent in fenestrations within the aortic lumen, whereas only self-expandable nitinol stents are placed in the branches to reinforce the placed stent. It could also be related to the anatomy as the choice for fenestrated EVAR requires endograft apposition, and as such, the distance between the orifice of the side branches and the endograft will be less.

In this study, mostly rigid balloon-expandable stents were used (Table III). More flexible bal-

loon-expandable stents may result in better outcome with B/F-EVAR.
In three cases, a cranial migration of the endograft was seen; in all those cases, >8 mm in aneurysm sac diameter change (growth in one and shrinkage in two) was noted. Large change in aneurysm sac size may consequently lead to aneurysm and aortic remodeling, pushing up the endograft.
At 5.3 years of follow-up, 21% of the branches had occluded. Greenberg et al[7] described 406 patients treated by branched EVAR, with only one occlusion after a mean follow-up of 15 months. In 2012, Reilly et al[23] presented a mean follow-up of 21 months in 81 patients with 306 branches. Eleven branches (4%) occluded, including nine renal arteries and two CelTrs. Mastracci et al14 described the 36-month results of patients treated with B/F-EVAR. The branch occlusion rate was only 1.7%, but it was higher in designs with branches only, being 5% at months of follow-up.[16] Most occlusions occur within the first few postprocedural months, but over time, the chance of occlusion remains, partly explaining the higher number in this study. However, Budtz-Lilly et al[24] showed an estimated cumulative freedom from branch instability at 3 years of 89%. Our study includes patients who were treated in the implementation phase of the technology and consequently includes the first cases that were treated in our clinic. A learning curve may thus have had a significant influence on our results.[25] Proctoring can assist surgeons with their first B/F-EVAR cases to improve selection and treatment strategies. Centralization may also increase the results of these highly complex cases.

Compared with current literature, we observed a lower adverse event-free survival rate of 90% for fenestrations and 59% for branches. In fenestrated EVAR for juxtarenal and short-neck infrarenal aneurysms, we previously reported an overall stent patency of 96% at 1 year and 89% at 4 years, underlining a higher patency of fenestrations.[26] The more complex construction probably makes branches more vulnerable than fenestrations to complications.[27]
The available studies use different ways to describe an adverse event, like stenosis or breaching of the stent. In our study, we tried to create a severity scale and considered stenosis >50% an adverse event. This more conservative view might result in a higher rate of adverse events than reported in studies mainly using only occlusion.
Migration of the endograft strains the stents in the branches and fenestrations, consequently leading to stent breach. The effect of migration and strain might be less in stented fenestrations because the aortic wall is adjacent to the endograft, consequently allowing less movement of

the endograft.[4,28] The difference in this study of adverse events for fenestrations and branches may be related to this effect but for now cannot be proven because of the combined design of branches and fenestrations in this small cohort.

Fragile patients who are unfit for open surgery might still benefit from an endovascular procedure. This selection bias might have influenced our sobering outcome. A substantial percentage (43%) of deaths during 5.3 years of follow-up was not aneurysm related. Patients who died within the first 30 days postoperatively merely reflect the fragility of our cohort (Table I). The clinical state of the patient may have been the reason for the choice of endovascular repair over open repair in the first place. All aneurysm-related deaths (n = 4) occurred after 4 to 6 years, indicating that careful follow-up is necessary even long after the primary procedure.

This study has limitations. First, it is a retrospective study with only 28 patients, all being among the first consecutive cases treated in our clinic. Most cases had a TAAA, some had a pAAA, all had a customized design, and different bridging stents were used (Table III), all of which make the group heterogeneous and not suitable for sub-analysis. Furthermore, the evolution in endograft design over time and combined branch and fenestration designs may have influenced the results. However, because of the long-term data, which are not available in most studies, and the specific emphasis on stent geometry, the study seems valuable.

Conclusions

After treatment of a TAAA or a pAAA by a branched endograft, the anatomic configuration changes during follow-up. The change in angle of branches and the bridging stent can lead to stenosis and occlusion. These risks seem lower in stented fenestrations compared with branches. Follow-up of branched EVAR should include measurements of anatomic change, including diameter of the aorta, endograft migration, target vessel stent length, and angulation, to detect and to prevent disconnection, stenosis, and occlusion.

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